Natural Resources Canada / Ressources naturelles Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8764

Relative sea-level projections for Canada based on the IPCC Fifth Assessment Report and the NAD83v70VG national crustal velocity model

T.S. James, C. Robin, J.A. Henton, and M. Craymer

2021

Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8764

Relative sea-level projections for Canada based on the IPCC Fifth Assessment Report and the NAD83v70VG national crustal velocity model

T.S. James[1], C. Robin[2], J.A. Henton[3], and M. Craymer[2]

[1]Geological Survey of Canada, 9860 West Saanich Road, Sidney, British Columbia
[2]Canadian Geodetic Survey, 588 Booth Street, Ottawa, Ontario
[3]Canadian Geodetic Survey, 9860 West Saanich Road, Sidney, British Columbia

2021

Permanent link: https://doi.org/10.4095/327878

This publication is available for free download through GEOSCAN (https://geoscan.nrcan.gc.ca/).

Recommended citation
James, T.S., Robin, C., Henton, J.A., and Craymer, M., 2021. Relative sea-level projections for Canada based on the IPCC Fifth Assessment Report and the NAD83v70VG national crustal velocity model; Geological Survey of Canada, Open File 8764, 1 .zip file, https://doi.org/10.4095/327878

Publications in this series have not been edited; they are released as submitted by the author.

Abstract. This report provides national and regional maps and national geospatial data files (geoTIFFs) of projected relative sea-level change across Canada for 2006 and every decade from 2010 to 2100. It updates and augments previous reports which included plots and tables of projected relative sea-level change at specified locations where a measurement of vertical land motion had been made by Global Positioning System (GPS). Here, gridded projections are provided at a resolution of 0.1° in latitude and longitude encompassing all coastal regions of Canada. The relative sea-level projections are based on the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) and on the NAD83v70VG national crustal velocity model. Projections are relative to 1986-2005, and are given for the median value and 5th and 95th percentiles for Representative Concentration Pathway (RCP) scenarios RCP2.6, RCP4.5, and RCP8.5. As well, the projected sea level at 2100 is given for an enhanced scenario where Antarctica is assumed to provide an additional 65 cm of global sea-level rise to the median projection of RCP8.5. For many purposes, the upper (95^{th} percentile) of the high-emission RCP8.5 scenario may comprise the appropriate planning level, but if tolerance to the risk of sea-level rise is low, it may be appropriate to consider a larger amount of projected sea-level rise.

Table of Contents

Introduction

This open file provides maps and geospatial data files of projected relative sea-level change for coastal locations in Canada and the adjacent mainland United States up to the year 2100. It updates and augments previously released Open File 7737 "Relative Sea-level Projections in Canada and adjacent mainland United States" (James et al., 2014) and "Tabulated Values of Relative Sea-level Projections in Canada and the Adjacent Mainland United States" (James et al., 2015). The previous reports included plots and tables of relative sea-level projections for 69 locations in Canada and the adjacent mainland United States where Global Positioning System (GPS) sites provided a measurement of vertical land motion. This report provides relative sea-level projections in a gridded format at a resolution of 0.1° in latitude and longitude, for the entire marine coastline of Canada, using a new model of vertical land motion across Canada.

Global sea-level change is the average amount of sea-level change over the world's oceans, relative to the centre of the Earth, and is sometimes described as 'absolute' sea-level change. Relative sea-level changes are the changes in sea level that are observed or experienced relative to the solid surface of the Earth. Land uplift can offset global sea-level rise, leading to reduced rise or even fall of relative sea level; on the other hand, land subsidence adds to absolute sea-level rise and increases relative sea-level rise. Relative sea-level rise leads to increased coastal flooding and erosion, depending on the physical nature of the coastline, while relative sea-level fall can lead to navigation hazards owing to reduced depth-under-keel (e.g., James et al., 2014; Lemmen et al., 2016; Bush and Lemmen, 2019). Projections of relative sea-level change are important for infrastructure planning and maintenance, forecasting risk to populations, transportation, and for habitat management (e.g., Nicholls et al., 2011).

The relative sea-level projections given here are based on the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) (Church et al., 2013a, b) and on the NAD83v70VG model of vertical land motion for Canada based on GPS observations (Robin et al., 2020). The vertical land motion model was augmented with the predictions of glacial isostatic adjustment (GIA) models to interpolate between spatially sparse observation sites, which is particularly important in the north. GIA is the response of the solid Earth to past and present-day fluctuations in the mass of glaciers and ice sheets. The land motion model allows sea-level projections to be produced for all coastal localities, not just sites where a GPS instrument has been installed and operated over a period of years.

Global and Relative Sea-level Changes and Vertical Land Motion

Global sea-level change arises from changes in the volume of water in the oceans (e.g., Church et al., 2013a). Warming of ocean water causes it to expand, increasing sea level. Meltwater from glaciers, ice caps, and ice sheets increases the amount of water in the oceans and also contributes to sea-level rise. Spatial variability in projected global sea levels arises from oceanographic currents, from the gravitational effects of shrinking ice masses, and spatial differences in ocean warming. Global sea-level changes are often referenced to the centre of the Earth.

Relative sea-level change is the change that is experienced relative to the solid Earth, and is the sea-level change that is experienced at the coastline that affects habitats, infrastructure, and human activity. Relative sea-level change is affected by vertical land motion, in addition to global sea-level change. Where land is rising rapidly, relative sea-level falls, while sinking land causes relative sea-level rise to be larger than the global value.

Over Canada, the land is rising in some areas and sinking in others, largely as a consequence of the delayed response to the last ice age (Figure 1). This process, called glacial isostatic adjustment (GIA), caused the land to subside under the weight of the ice sheets during the ice age. Deep within the Earth, mantle rock flowed ductilely in response to the surface load. Near the periphery, and outside, the former ice sheet, the land rose where mantle material was displaced outwards from the centre of the ice load. During and following deglaciation, the land motions are reversed. Depressed regions started to rise and elevated regions began to fall. The process is still continuing today, a consequence of the large values of viscosity (resistance to flow) of the Earth's mantle.

The land is rising rapidly in the Hudson Bay region and over much of the Canadian Arctic Archipelago (Figure 1). Much of the Maritimes, and the Beaufort coastline, is sinking. Another process that contributes to land motions is sediment compaction, important where there are thick sequences of recently deposited sediments, such as on large deltas like the Fraser and Mackenzie deltas (Mazzotti et al., 2008; Forbes et al., 2005). Tectonic effects, such as slow creep on faults and land displacements generated by large earthquakes, can also generate vertical land motions that influence relative sea levels. The relative sea-level projections presented here account for regional vertical land motion due to GIA, but not localized enhanced ground subsidence due to sediment compaction and groundwater withdrawal. Over much of Canada, the contribution of vertical land motion to projected relative sea-level is sea-level fall (Figure 2).

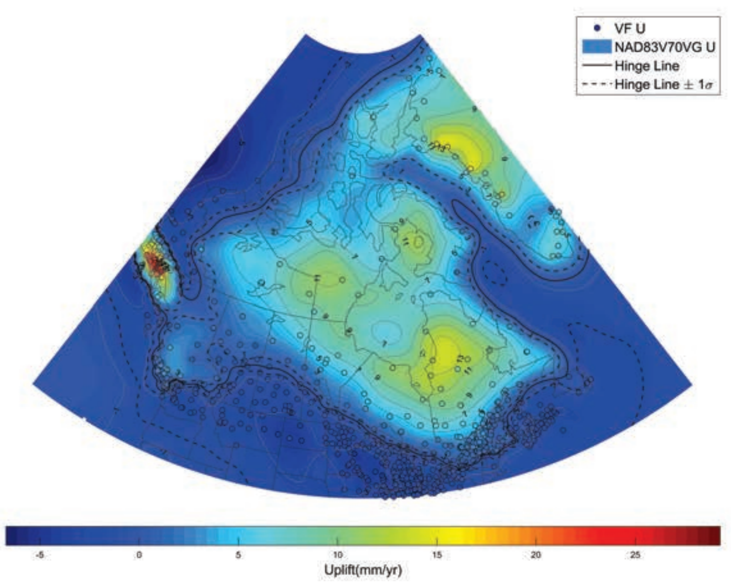


Figure 1. Land uplift rates for the NAD83V70VG model (Robin et al., 2020) in millimetres per year. The hinge line (thick black line) is the zero contour between uplift and subsidence.

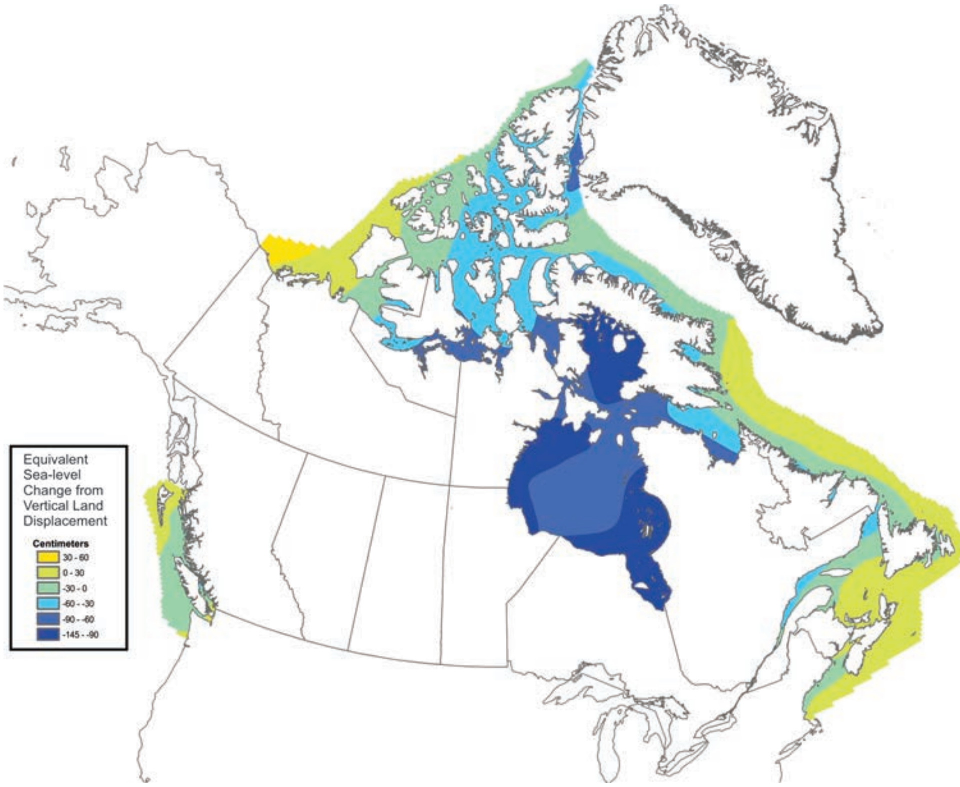


Figure 2. Contribution of vertical land motion to projected sea-level change at 2100. The contribution is determined by converting uplift rates (Robin et al., 2020) to equivalent relative sea-level change rates, taking into account changes to the geoid (James et al., 2014), and scaling by the elapsed time.

Methods

As reviewed by James et al. (2014), the global sea-level rise projections generated for the IPCC AR5 (Church et al., 2013a) incorporated contributions from glaciers and ice sheets, the thermo-steric expansion of the ocean, and direct anthropogenic contributions from groundwater pumping and construction of water reservoirs. IPCC AR5's relative sea-level projections also included spatially-varying effects such as sea-level fingerprinting and dynamic oceanographic effects, and vertical land motion based on the average of two GIA model predictions (ICE-5G (Peltier, 2004) and the Australian National University (ANU) model (Lambeck et al., 1998 and subsequent improvements)). For improved sea-level projections on the Canadian coast, global GIA model predictions were removed from the IPCC AR5 regional sea-level projections and replaced by the NAD83v70VG vertical land motion, following methods described by James et al. (2014), in a Geographic Information System (GIS) environment. The relative sea-level projections generated for the IPCC AR5 (Church et al., 2013a) were provided on global 1º by 1º grids and are available at this link: https://icdc.cen.uni-hamburg.de/en/ar5-slr.html. After removing the GIA model predictions used in the AR5's relative sea level projections, the residuals were spatially extrapolated from the ocean basins to the coastline and merged with the NAD83v70VG vertical land motion (available at https://webapp.geod.nrcan.gc.ca/geod/tools-outils/nad83-docs.php?locale=en) to generate new relative sea-level projections that incorporate recent measurements of vertical land motion in Canada.

The new sea-level projections were compared to the old projections at the previously reported GPS sites to assess their consistency (Appendix A). Agreement is good, with some variability arising from changes to the vertical crustal motion and from adoption of GIS-based methods for extrapolation and resampling of gridded data. After correcting the new projections for the changes in vertical velocity arising from the new model of vertical land motion, the agreement between the new and old projections improves further (Appendix B).

Contents of this Report

Representative Concentration Pathways (RCP) scenarios (Moss et al., 2010) were prepared for the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). The scenarios are representative of a much larger group of emissions scenarios and provide different pathways of greenhouse gas concentration through the 21st century. The number in each scenario name corresponds to the net radiative forcing (in W m^{-2}) at 2100, where the net radiative forcing is the difference between the amount of energy that enters the Earth's atmosphere and the amount that is radiated away from the Earth. Larger amounts of net radiative forcing correspond to larger amounts of projected global atmospheric temperature rise (Table 1).

In this report, relative sea-level projections are provided in geospatial data format (geoTIFF format) and as national and regional maps (PDF format) (Figure 3) for 2006 and for every decade from 2010 to 2100. The projections are provided for Representative Concentration Pathway (RCP) scenarios RCP2.6, RCP4.5, and RCP8.5 for the median and 5th and 95th percentile values (Figure 4). In addition, the average projections for the time period 2081-2100 include RCP6.0 and are given for the median and 5th and 95th percentile values in map and geospatial data formats. Finally, the relative sea-level projection at 2100 is provided for an enhanced scenario that provides an additional 65 cm of global sea-level rise sourced from the West Antarctic Ice Sheet and added to the median projection of RCP8.5. The corresponding amount of projected global sea-level rise at 2100 is given in Table 2 for each scenario.

Figure 3. Location map indicating the extents of the national and four regional map area

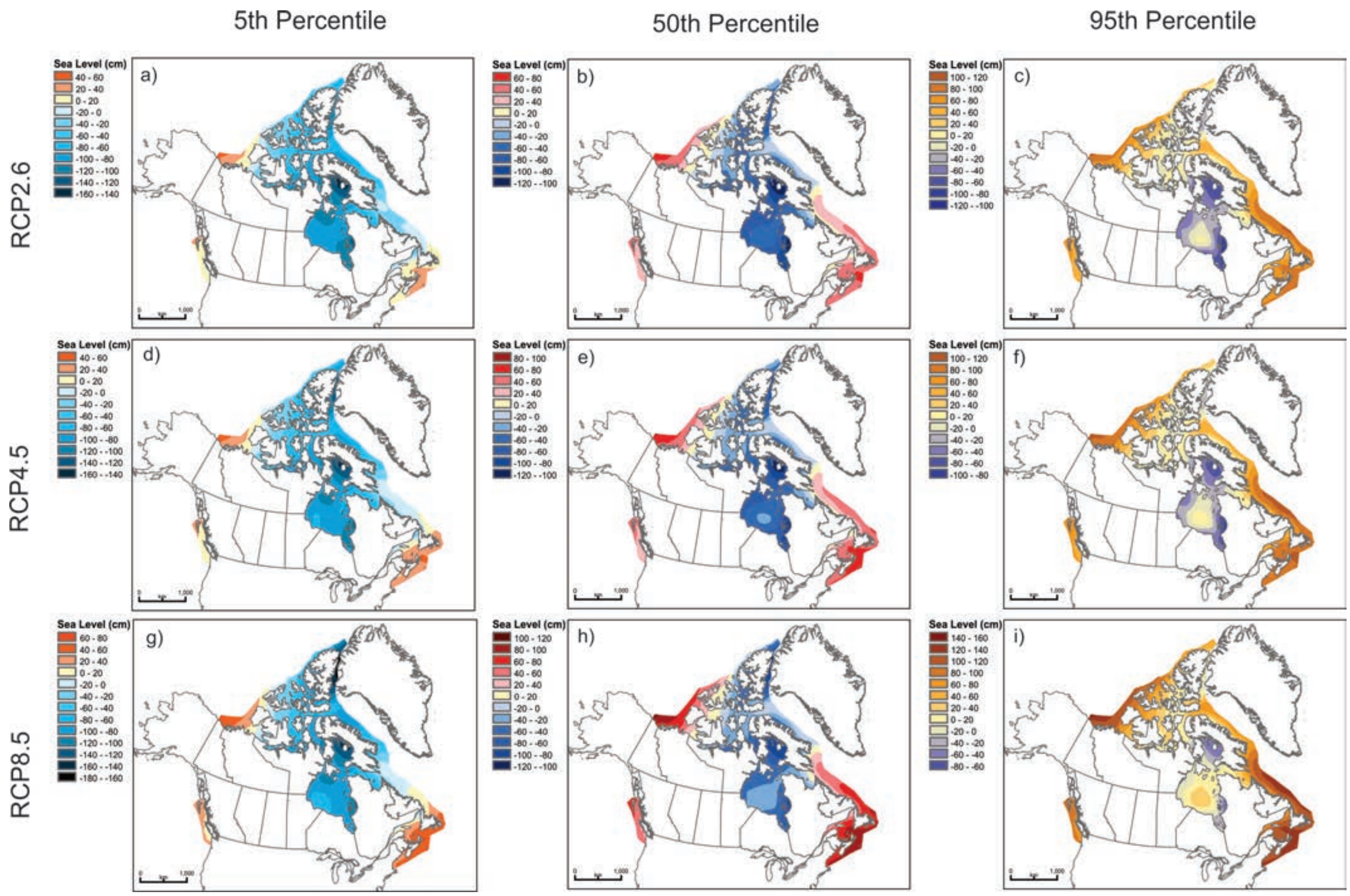


Figure 4. Maps of projected relative sea-level change for Canada at 2100 for (a-c) low-emission scenario RCP2.6, (d-f) medium-emission scenario RCP4.5, and (g-i) high-emission scenario RCP8.5 for the 5th, 50th (median), and 95th percentiles in the left-hand, centre, and right-hand panels, respectively. Projections are relative to the average conditions in the 1986–2005 period. To facilitate comparisons across a scenario (i.e., in the horizontal), all colour scales feature a bright yellow for 0 to 20 cm of relative sea-level rise. To facilitate comparisons across scenarios (i.e. in the vertical), the same colour scale is used for all maps of the same percentile value, but the legend range varies for each panel.

Table 1. Projected Global Atmospheric Temperature Increase (°C) by Representative Concentration Pathway Scenario[1]

	2046-2065[2]	2081-2100
Representative Concentration Pathway (RCP) Scenario	Mean and likely range[3]	Mean and likely range
Low (RCP2.6)	1.0 (0.4 to 1.6)	1.0 (0.3 to 1.7)
Medium (RCP4.5)	1.4 (0.9 to 2.0)	1.8 (1.1 to 2.6)
High (RCP8.5)	2.0 (1.4 to 2.6)	3.7 (2.6 to 4.8)

[1]Table SPM-2, IPCC, 2013.

[2]Projections are given relative to a baseline of 1986-2005.

[3]Likely range encompasses the 5th to 95th percentiles of the model ensemble range.

Table 2. Projected global sea-level rise by 2100[1]

Emission scenario	Likely global sea-level rise by 2100 (cm), median [90% uncertainty range][2]
Low (RCP2.6)	44 [28 to 61]
Medium (RCP4.5)	53 [36 to 71]
High (RCP8.5)	74 [52 to 98]
Enhanced; RCP8.5 plus Antarctic ice sheet reduction[3]	74 + 65 = 139

[1]Church et al., 2013a

[2]Relative to 1986–2005.

[3]Scenario is indicative, so percentile values (uncertainty range) are not provided. Development of the Enhanced scenario described in James et al., 2014.

The maps were generated with three different colour scales: a cool scale for the 5th percentile, neutral for the median (50th percentile) and a warm scale for the 95th percentile (Figure 4). All colour scales feature a bright yellow for 0 to 20 cm of relative sea-level rise. To facilitate comparison across scenarios, the same colour scale is used for all scenarios, but the legend range varies for each panel. Owing to the much larger values of projected relative sea-level rise given by the enhanced scenario (which is only provided for the year 2100), it utilizes the neutral (median) colour scale, but with additional colours added to the high end (Figure 5).

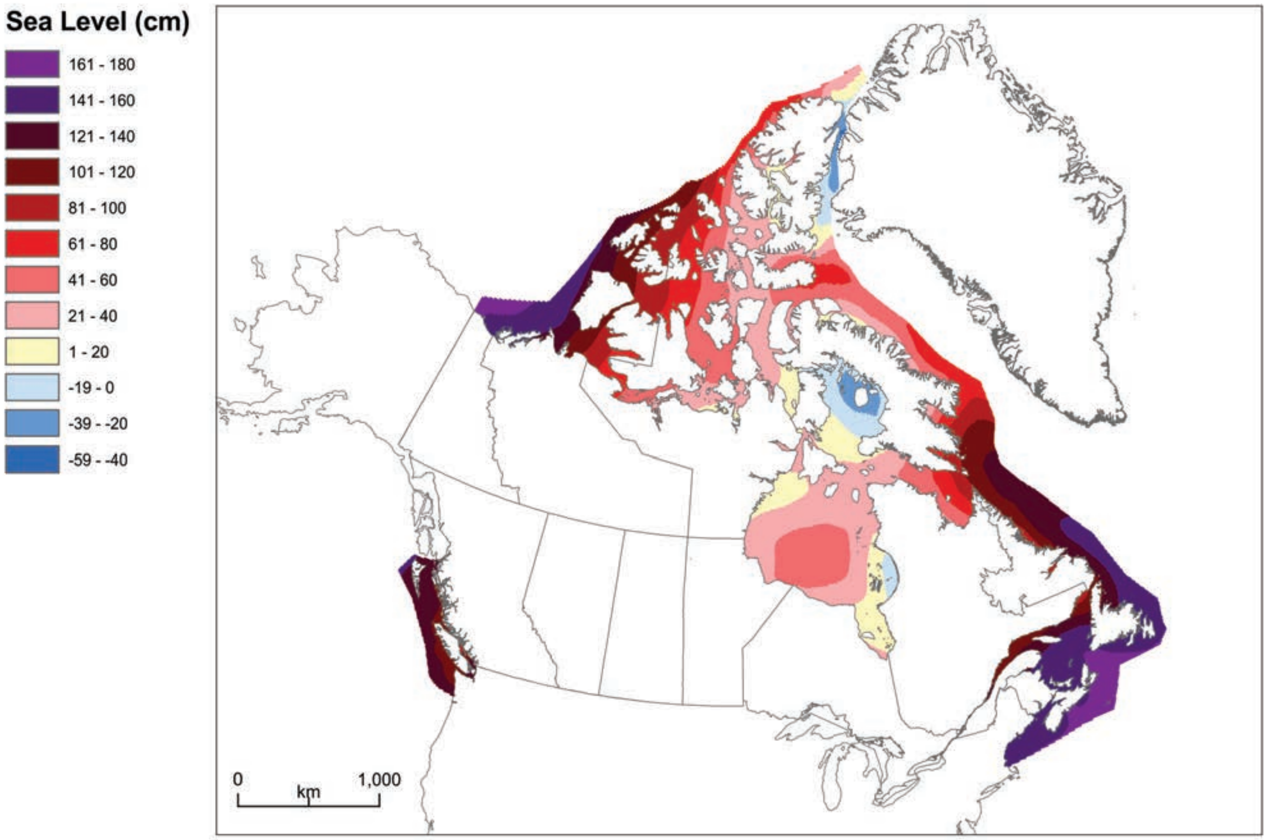


Figure 5. Projected relative sea-level at 2100 for the enhanced scenario, which features an additional 65 cm of sea-level rise sourced from West Antarctica and added to the median of RCP8.5. Projection is relative to average conditions from 1986 to 2005.

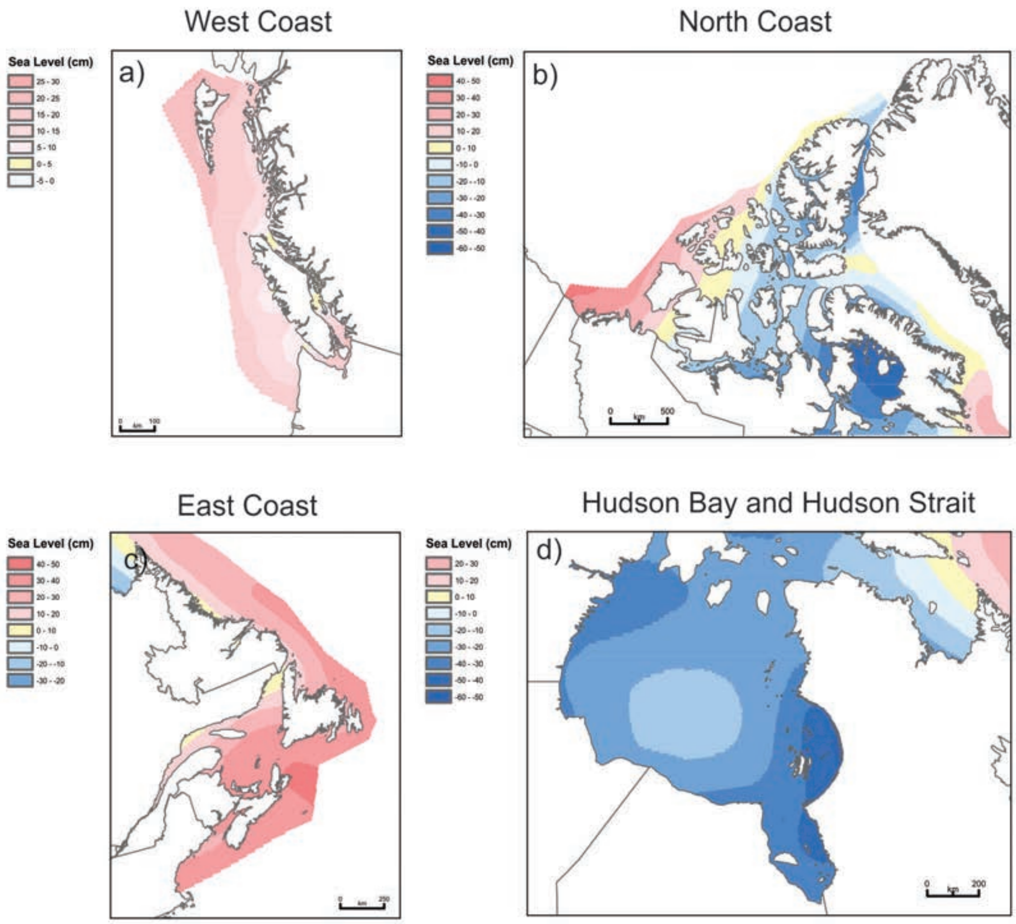


Figure 6. Projected median relative sea-level at 2050 for high-emission scenario RCP8.5 for four regions: (a) west coast, (b) north coast, (c) east coast, and (d) Hudson Bay and Hudson Strait. Projections are relative to average starting conditions at 1986 to 2005.

Regional maps provide higher-resolution imagery for the west coast, east coast, north coast, and for Hudson Bay and Hudson Strait (Figures 3 and 6), compared to the national maps. The regional maps employ the same colour scales as the national maps. Most of the regional maps have a range of negative and positive projected sea-level change, and the legends exhibit a range of colours differentiating between different amounts of sea-level change projected at different locations. An exception is the west coast (e.g., Figure 4a), where the relatively limited range of projected sea-level rise produces maps with a limited colour palette. The interested reader is invited to generate maps reflecting their specialized interests from the geospatial data files, and may be especially motivated to do so for the west coast.

The grid resolution of 0.1° corresponds to about 11 km in latitude, while in longitude it ranges from about 8 km in southern Canada (southern Ontario) to about 2 km in northern Canada at the northern extent of Ellesmere Island. The differing east-west (longitude) resolution reflects the decreased spacing of lines of equal longitude towards the poles, compared to equatorial regions.

Guidance for use of relative sea-level projections

The relative sea-level projections provided here indicate the amount by which relative (mean) sea-level is projected to rise, compared to the average conditions in the 1986 to 2005 period. The following describes some considerations for the use of relative sea-level projections, updated from James et al. (2014). It does not supersede the sea-level change guidance provided in some jurisdictions, nor does it exhaustively catalogue all the possible considerations.

The projections are based on the 5th Assessment Report of the IPCC (IPCC, 2013; Church et al., 2013a). High-emission scenario RCP8.5 incorporates the upper end of the likely range of the RCP scenarios. The upper range (95th percentile) may therefore be of particular relevance to management and planning in coastal areas. The different Representative Concentration Pathways scenarios reflects possible pathways of future carbon emissions. The spread of model projections for a given RCP reflects the range of model output produced by different modelling centres, and also incorporates the uncertainty in the crustal velocity model. Generally, the range of model projections for a given RCP generates a larger range of sea-level projections than the differences among the different scenarios (Figure 4).

In cases where tolerance to the risk of sea-level rise is very low, it may be appropriate to consider larger amounts of global sea-level rise, such as that given by the enhanced scenario. The enhanced scenario (1.39 m of global sea-level rise by 2100; see Table 1) addresses the question of the stability of marine-based portions of the Antarctic Ice Sheet, and its potential to deliver much larger amounts of water to the oceans than most present models deliver (James et al., 2014). Projected amounts of sea-level rise even larger than the enhanced scenario may be possible. The United States Fourth National Climate Assessment (NCA4) report (Sweet et al., 2017) provides scenarios ranging up to 2.5 m of global sea-level rise, noting that low probabilities are assigned to the highest scenarios (1.5, 2, and 2.5 m). The "extreme" scenario of 2.5 m of global sea-level rise by 2100 is intended to "test plans and policies against extreme cases with a low probability of occurrence but severe consequences if realized" (Sweet et al., 2017).

For planners wishing to consider these larger amounts of sea-level rise, the spatial pattern of relative sea-level rise in Canada could be approximated by adding the additional global sea-level rise to the median projection of RCP8.5 or to the enhanced scenario, keeping mind that the median projection of RCP8.5 gives 0.74 m of sea-level rise by 2100, while the enhanced scenario provides 1.39 m. This approach would not include all the regional effects caused by gravitationally-driven melt-water redistribution, but would provide a first-order approximation of projected sea-level rise for extreme cases.

Alternatively, an adaptive planning approach, such as Adaptation Pathways (Hasnoot et al., 2012; 2013) or other robust adaptation methods would consider a range of probable projected sea-level change values, probably extending beyond the immediate planning time horizon, and consider resilient designs that could be adapted in the future if circumstances required changes to the design or use. Such an approach can reduce immediate expenditures, and provide assurance that a plan is in place for alternative future plausible conditions. It allows planning, execution, and operations to take place in the absence of certainty about future sea levels.

For comparative analyses of the costs of mitigation and adaptation, comparisons between a high-emissions scenario (RCP8.5) and a low-emission scenario (RCP2.6, strong mitigation), may be useful. Here the impacts and costs of climate change for differing pathways of carbon emissions can be assessed, and compared to the costs of mitigation.

In many locations in northern Canada, relative sea-level is projected to fall. Rather than the issues of inundation and flooding that accompany sea-level rise, the potential issues are ones of navigation hazards brought about by reduced depth-under-keel of vessels, and the reduced usefulness of coastal infrastructure over time brought about by lower water levels (e.g., James et al., 2014; Atkinson et al., 2016). The latter suggests that projected lower water levels should be incorporated into the design life-cycle of coastal infrastructure where appropriate.

The hazards and risks posed by relative sea-level change, which is projected to both rise and fall depending on the location in Canada, vary across Canada. For rising sea-levels, the hazards range from flooding, coastal erosion, habitat change, and impacts on coastal infrastructure, while for falling sea levels the hazards and risks include navigation hazards, impacts on coastal infrastructure, and habitat change. Because of these varying hazards, varying planning and management time lines, and varying levels of risk tolerance, the scenarios under consideration, percentile values, and timelines will vary across users.

Limitations to the Sea-level Projections

The sea-level projections are based on a national model of vertical crustal motion derived from GPS measurements (Robin et al., 2020). For the purposes of establishing national geodetic reference frames, GPS antenna are usually installed on monuments fixed to bedrock, and in some cases to long-established masonry buildings. In rare circumstances, other ways of establishing a link to the ground are utilized, such as mounting the antenna on a wooden pole frozen into permafrost-rich sediments (as is the case for Tuktoyaktuk). The consequence of this approach is that the crustal velocity model, for the most part, reflects the vertical motion of underlying bedrock. To ensure a smoothly varying national crustal velocity field, sites exhibiting anomalous vertical motion, compared to other nearby sites, were also removed before determining the final velocity field. The reasons for anomalous velocities at some sites arise from monument instability, short time series, or equipment failure, but some sites were removed with anomalous vertical motion that may relate to local enhanced subsidence.

In locations with thick sequences of unconsolidated sediments, such as on deltas, that are undergoing local compaction and subsidence, the crustal velocity model therefore may not reflect the actual ground subsidence. In this case, the sea-level projection given here would underestimate the amount of projected sea-level rise. Thus, caution is advised in applying the sea-level projections given here in locations where local ground subsidence is suspected or has been demonstrated. For example, large deltas such as those at the mouth of the Fraser and Mackenzie rivers are subject to autocompaction and other local subsidence (e.g., Mazzotti et al., 2009), which contribute to increased flood risk and potential habitat loss through inundation by relative sea-level rise. For the Fraser delta, the background rate of surface subsidence is estimated to be 1 to 2 mm/yr, but locally may be much larger where large structures have recently been built, or where groundwater pumping is taking place (e.g., Samsonov et al., 2014). Thus, caution is called for in locations where the surface is underlain by thick sequences of unconsolidated sediments and in this case the reader may wish to seek out possible local sources of information on land subsidence.

The sea-level projections presented here extend to the year 2100, but sea-level is projected to continue to rise beyond that time. In cases where long-term adaptive planning is being contemplated, consideration of sea-level change beyond 2100 is necessary. Work is presently underway to update and extend the sea-level projections beyond 2100.

Summary

The maps and geospatial data files provided here give quantitative information on projected relative sea-level change for all coastal locations in Canada. They may be of use for planning, management, and risk analysis purposes, to assess the probable costs of climate change impacts in coastal regions, and to assess the benefits of mitigation pathways. The reader is referred to Church et al. (2013a, b) and James et al. (2014) for background and methods for deriving the relative sea-level projections, for explanation of scenarios, and for more information on scope and limitations of the projections.

Acknowledgments.

We acknowledge ongoing support from the Climate Change Impacts and Adaptation Division, Land and Minerals Sector (LMS), NRCan. We gratefully acknowledge the advice and encouragement provided by Mary-Ann Wilson, Don Lemmen, and John Sommerville. The AR5 sea-level projections were obtained from the Integrated Climate Data Center at the University of Hamburg and can be obtained at http://icdc.cen.uni-hamburg.de/1/daten/ocean/ar5-slr.html. Roger MacLeod and Rob Kung are thanked for providing GIS advice and support. We thank a dedicated corps of Coop students, including Connor Brierley-Green, Tyler Schamehorn, William Liu, Rowan Simms-Riddell, Thea Mai, and Hana Hourston for providing GIS and Python coding support for the development of these projections. This is an output of the LMS Climate Change Geoscience Program.

References

Atkinson, D.E., Forbes, D.L. and James, T.S. (2016): Dynamic coasts in a changing climate; in Canada's Marine Coasts in a Changing Climate, (ed.) D.S. Lemmen, F.J. Warren, T.S. James and C.S.L. Mercer Clarke; Government of Canada, Ottawa, ON, p. 27-68.

Bush, E. and Lemmen, D.S., editors (2019): Canada's Changing Climate Report; Government of Canada, Ottawa, ON. 444 p. Available online at: https://changingclimate.ca/CCCR2019/

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013a. Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013b. Sea Level Change Supplementary Material. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)].

Haasnoot, M., H. Middelkoop, A. Offermans, E. van Beek, W. P. A. van Deursen, 2012. Exploring pathways for sustainable water management in river deltas in a changing environment, Climatic Change (2012) 115:795–819, DOI 10.1007/s10584-012-0444-2.

Haasnoot, M., J. H. Kwakkel, W. E. Walker, J. ter Maat, 2013. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world, Global Environmental Change 23 (2013) 485–498.

IPCC, 2013. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

James, T.S., Henton, J.A., Leonard, L.J., Darlington, A., Forbes, D.L., and Craymer, M., 2014. Relative Sea-level Projections in Canada and the Adjacent Mainland United States; Geological Survey of Canada, Open File 7737, 72 p. doi:10.4095/295574.

James, T.S., Henton, J.A., Leonard, L.J., Darlington, A., Forbes, D.L., and Craymer, M., 2015. Tabulated values of relative sea-level projections in Canada and the adjacent mainland United States; Geological Survey of Canada, Open File 7942, 81 p. doi:10.4095/297048.

Lambeck, K., C. Smither, and P. Johnston, 1998. Sea-level change, glacial rebound and mantle viscosity for northern Europe. Geophys. J. Int., 134, 102–144.

Lemmen, D.S., Warren, F.J., James, T.S. and Mercer Clarke, C.S.L. editors (2016): Canada's Marine Coasts in a Changing Climate; Government of Canada, Ottawa, ON, 274p.

Mazzotti, S., Lambert, A., Van der Kooij, M., and Mainville, A. (2009): Natural and anthropogenic subsidence of the Fraser River Delta; Geology, v. 37; no. 9, p. 771–774, doi:10.1130/G25640A.1

Nicholls, R.J., Hanson, S.E., Lowe, J.A., Warrick, R.A., Lu, X., Long, A.J. and Carter, T.A. (2011): Constructing sea-level scenarios for impact and adaptation assessment of coastal areas: a guidance document; Intergovernmental Panel on Climate Change (IPCC), Task Group on Data and Scenario Support for Impact and Climate Analysis, Geneva,

Switzerland, 47 p., <http://www.ipccdata.org/docs/Sea_Level_Scenario_Guidance_Oct2011.pdf>.
Peltier, W.R., 2004. Global glacial isostasy and the surface of the ice-Age Earth: The ICE-5G (VM2) model and GRACE, Ann. Rev. Earth and Planet. Sci., 32, 111-149.
Robin, C.M.I., Craymer, M., Ferland, R., James, T.S., Lapelle, E., Piraszewski, M., and Zhao, Y., 2020. NAD83v70VG: A new national crustal velocity model for Canada; Geomatics Canada, Open File 0062, 1. zip file. https://doi.org/10.4095/327592
Samsonov, S.V., N.d'Oreye, P. J. González, K. F. Tiampo, L. Ertolahti, J. J. Clague, 2014. Rapidly accelerating subsidence in the Greater Vancouver region from two decades of ERS-ENVISAT-RADARSAT-2 DInSAR measurements, Rem. Sensing Env., 143, 180–191.
Sweet, W.V., Kopp, R.E., Weaver, C.P., Obeysekera, J., Horton, R.M., Thieler, E.R. and Zervas, C. (2017): Global and regional sea level rise scenarios for the United States; NOAA Technical Report NOS CO-OPS 083, Silver Spring, Maryland.

Appendix A: Comparison of New Sea-Level Projections to Old

The new sea-level projections (this study) were compared to old sea-level projections (James et al., 2014; 2015) on scatter plots (Figure A1). For perfect correspondence, the slope of the derived line and the R^2 of the fit would both be one, while the y-intercept would be zero. The derived statistics of the best-fitting straight lines indicate that agreement is generally good (Tables A1-A3), with slopes ranging from 0.96 to 1.02, y-intercepts ranging from -0.3 to +3.0 cm, and R^2 goodness of fits larger than 0.97. Compared to the velocity-corrected sea-level comparison (see Appendix B), the differences are larger, but there is general consistency in sea-level projections at the GPS sites considered by James et al. (2014; 2015). The differences arise in part because the crustal velocity model is not a strict interpolation, but is a fit for each site taking measurement errors into account, and in part because the extrapolated and resampled fields of projected sea-level change were generated using built-in ArcGIS functions in this study, which differs slightly from the extrapolation carried out by James et al. (2014).

Table A1. Fifth Percentile (LOWER) comparison between old and new sea-level projections.

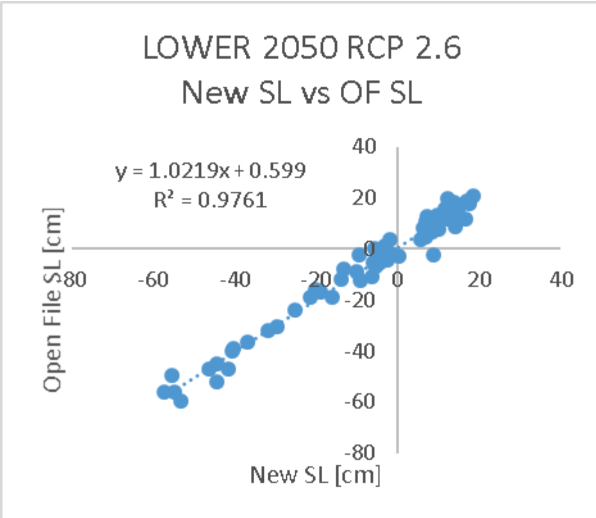
Year	RCP 2.6			RCP 4.5			RCP 8.5		
	slope	y-intercept	R^2	slope	y-int.	R^2	slope	y-int.	R^2
2050	1.022	0.599	0.976	1.013	0.781	0.973	1.004	-0.226	0.979
2100	1.014	1.108	0.982	1.013	1.327	0.982	1.013	1.285	0.987

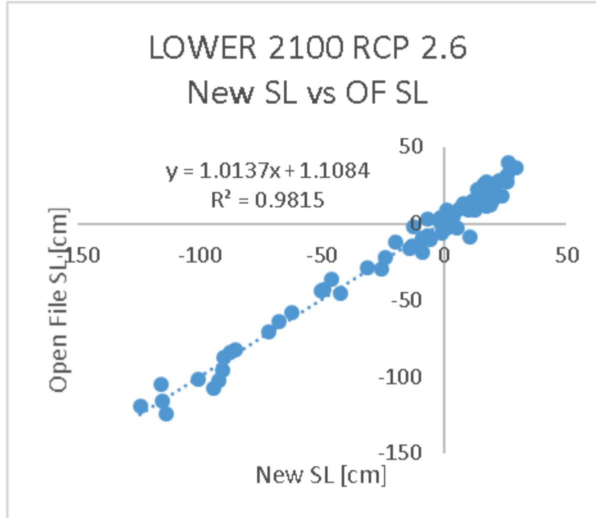
Table A2. Fiftieth Percentile (Median) comparison between old and new sea-level projections.

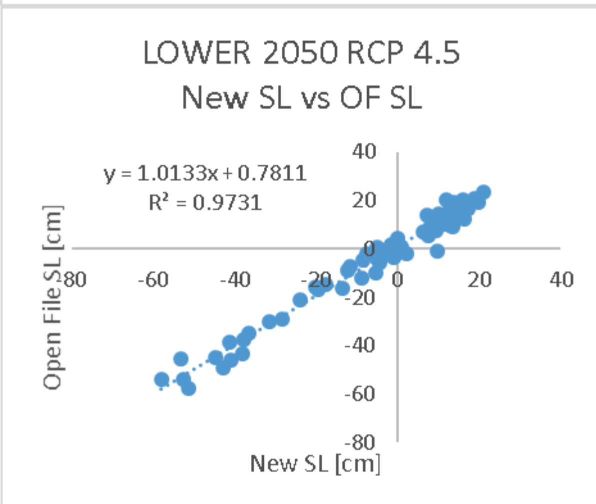
Year	RCP 2.6			RCP 4.5			RCP 8.5		
	slope	y-intercept	R^2	slope	y-int.	R^2	slope	y-int.	R^2
2050	1.019	0.272	0.977	0.993	0.008	0.977	0.984	-0.141	0.977
2100	1.020	2.083	0.982	1.020	2.022	0.982	1.020	1.900	0.983

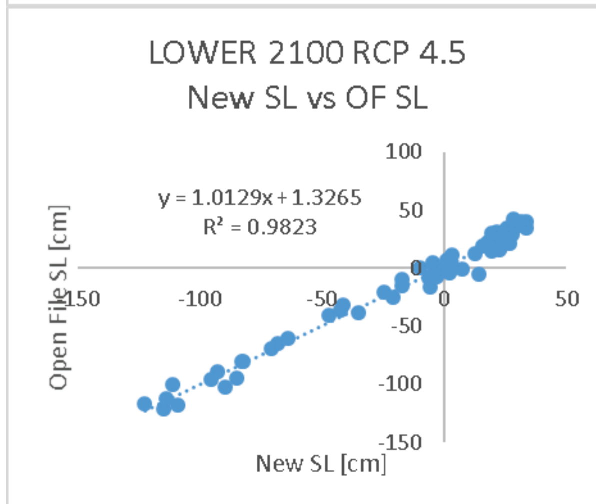
Table A3. Ninety-fifth Percentile (UPPER) comparison between old and new sea-level projections.

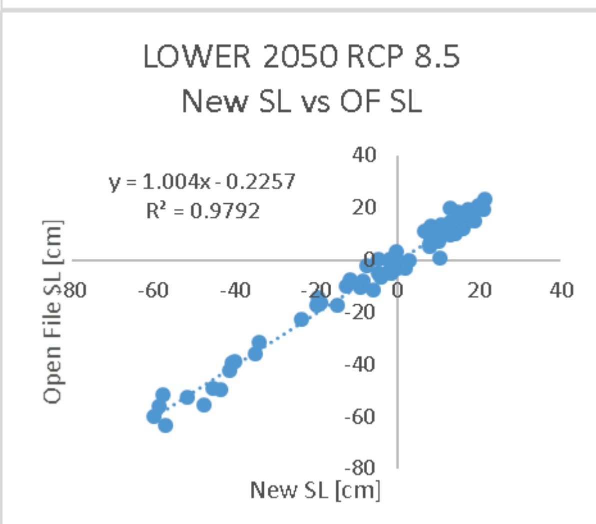
Year	RCP 2.6			RCP 4.5			RCP 8.5		
	slope	y-intercept	R^2	slope	y-int.	R^2	slope	y-int.	R^2
2050	1.007	0.151	0.975	0.969	-0.262	0.976	0.962	0.532	0.973
2100	1.02	2.96	0.980	1.022	2.525	0.981	1.020	2.490	0.978

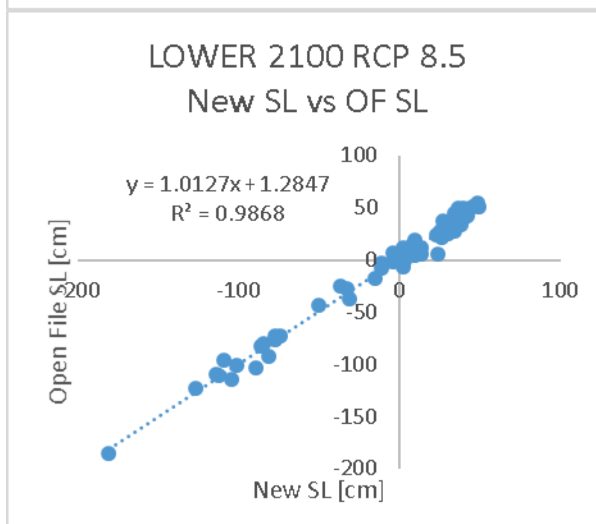

LOWER 2050 RCP 2.6
New SL vs OF SL
y = 1.0219x + 0.599
R² = 0.9761
Open File SL [cm]
New SL [cm]

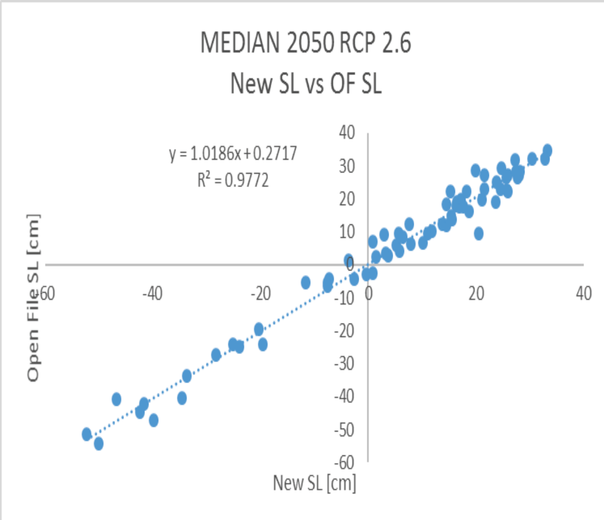

LOWER 2100 RCP 2.6
New SL vs OF SL
y = 1.0137x + 1.1084
R² = 0.9815
Open File SL [cm]
New SL [cm]

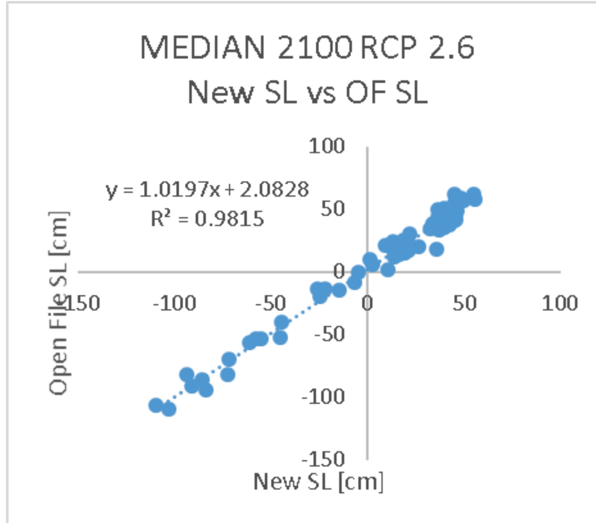

LOWER 2050 RCP 4.5
New SL vs OF SL
y = 1.0133x + 0.7811
R² = 0.9731
Open File SL [cm]
New SL [cm]

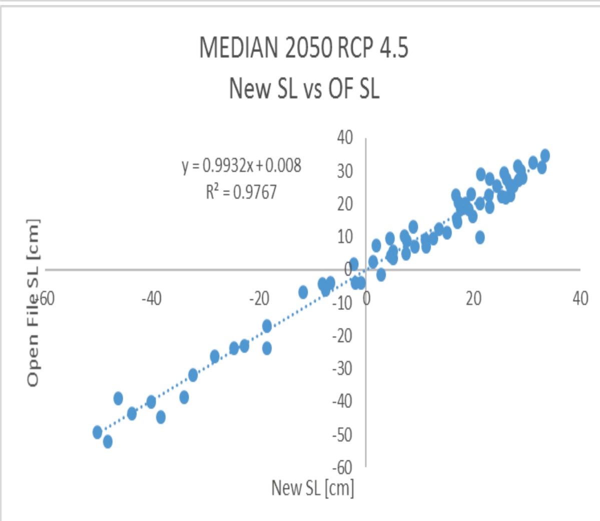

LOWER 2100 RCP 4.5
New SL vs OF SL
y = 1.0129x + 1.3265
R² = 0.9823
Open File SL [cm]
New SL [cm]

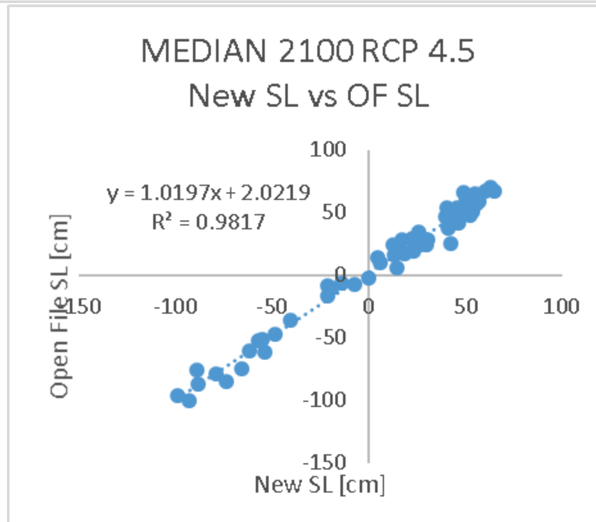

LOWER 2050 RCP 8.5
New SL vs OF SL
y = 1.004x - 0.2257
R² = 0.9792
Open File SL [cm]
New SL [cm]

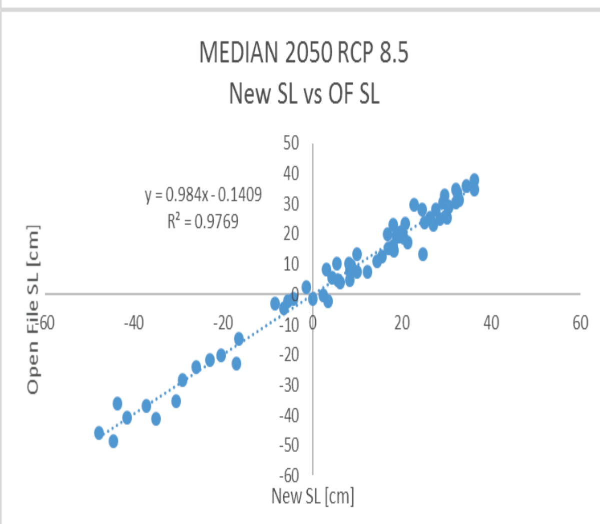

LOWER 2100 RCP 8.5
New SL vs OF SL
y = 1.0127x + 1.2847
R² = 0.9868
Open File SL [cm]
New SL [cm]

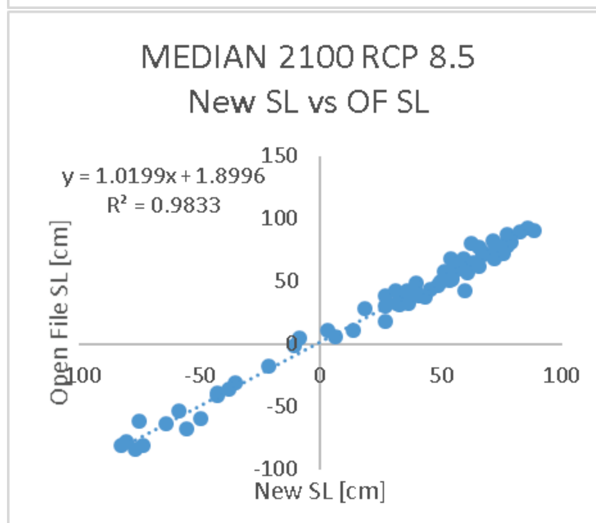

MEDIAN 2050 RCP 2.6
New SL vs OF SL
y = 1.0186x + 0.2717
R² = 0.9772
Open File SL [cm]
New SL [cm]


MEDIAN 2100 RCP 2.6
New SL vs OF SL
y = 1.0197x + 2.0828
R² = 0.9815
Open File SL [cm]
New SL [cm]


MEDIAN 2050 RCP 4.5
New SL vs OF SL
y = 0.9932x + 0.008
R² = 0.9767
Open File SL [cm]
New SL [cm]


MEDIAN 2100 RCP 4.5
New SL vs OF SL
y = 1.0197x + 2.0219
R² = 0.9817
Open File SL [cm]
New SL [cm]


MEDIAN 2050 RCP 8.5
New SL vs OF SL
y = 0.984x - 0.1409
R² = 0.9769
Open File SL [cm]
New SL [cm]


MEDIAN 2100 RCP 8.5
New SL vs OF SL
y = 1.0199x + 1.8996
R² = 0.9833
Open File SL [cm]
New SL [cm]

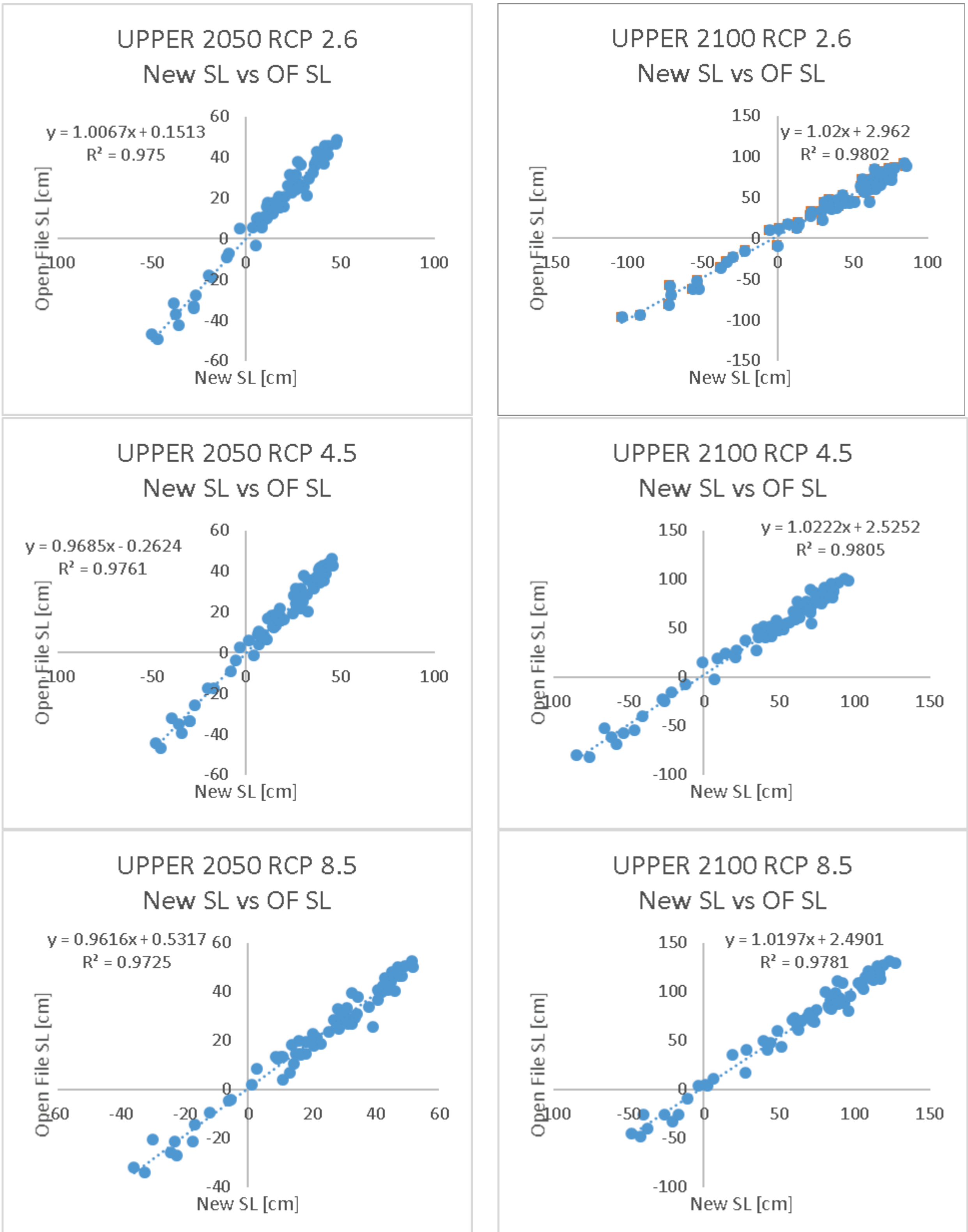


Figure A1. Scatter plots of old (Open file SL, James et al., 2014; 2015) versus new (New SL; this study) sea-level projections and derived statistics (slope, y-intercept, and R^2 goodness of fit) of the best-fitting straight line for 5th (LOWER), 50th (MEDIAN) and 95th (UPPER) percentiles of RCP2.6, RCP4.5, and RCP8.5.

Appendix B: Consistency Analysis Accounting for Crustal Velocity Differences

To further assess the consistency of the new sea level projections, a comparison was carried out with the previously published sea-level predictions (James et al., 2014; 2015) in which a correction was made for the change in vertical land motion. For the median projections, the difference in projected sea-level between the new velocity model and the measured velocity as given by James et al. (2014) was removed from the new prediction (equation 1), using the empirical relationship between vertical land motion and change in local sea level derived by James et al. (2014, Appendix B).

$$slr_{vel}[cm] = \frac{\Delta velocity[mm/yr] \times -0.91 \times (Year - 1995)}{10} \qquad (1)$$

where $\Delta velocity$ is the difference in velocity between the new and old projections, slr_{vel} is the correction to the projected sea-level value, and the factor of 1/10 converts from millimetres to centimetres. The corrected new sea-level projection $slr_{toCompare}$ which is compared to the old sea-level projection is then given by:

$$slr_{toCompare} = slr_{new} - slr_{vel}$$

Similar corrections were made for the 5th (LOWER) and 95th (UPPER) percentile sea-level projections. Velocity-corrected new sea-level projections were scatter-plotted against old sea-level projections, and a best-fitting straight line was derived using least-squares methods. For an ideal comparison, the slope of the derived line and the R^2 of the fit would both be one, while the y-intercept would be zero.

Results of the comparisons are given for RCP2.6 (Table 1), RCP4.5 (Table 2) and RCP8.5 (Tables B1-B3). Agreement between the velocity-corrected new sea-level projections and old sea-level projections is very good, with slopes near 1 (0.98 to 1.02), R^2 of 0.997 and larger, and y-intercepts ranging from -2.1 cm to +1.7 cm. The small differences indicate that the extrapolated oceanographic fields, extrapolated using GIS functionality in this study, differ slightly from the extrapolation carried out by James et al. (2014).

Table B1. Reported accuracy of the lower, median, and upper projections at 2050 and 2100 for RCP2.6.

RCP 2.6				
Scenario	Year	Slope	Y-Intercept [cm]	R^2
LOWER	2100	0.997	-0.24	0.9996
LOWER	2050	1.000	0.87	0.9986
MEDIAN	2100	1.003	-2.13	0.9992
MEDIAN	2050	1.002	-1.91	0.9973
UPPER	2100	1.001	0.16	0.9996
UPPER	2050	0.996	-0.81	0.9989

Table B2. Reported accuracy of the lower, median, and upper projections at 2050 and 2100 for RCP4.5.

RCP 4.5				
Scenario	Year	Slope	Y-Intercept [cm]	R^2
LOWER	2100	0.997	-0.09	0.9998
LOWER	2050	1.021	1.71	0.9983
MEDIAN	2100	1.004	-2.09	0.9993
MEDIAN	2050	0.977	-2.11	0.9979
UPPER	2100	1.002	-0.04	0.9998
UPPER	2050	0.978	-1.25	0.9985

Table B3. Reported accuracy of the lower, median, and upper projections at 2050 and 2100 for RCP8.5.

RCP 8.5				
Scenario	Year	Slope	Y-Intercept [cm]	R^2
LOWER	2100	0.996	-0.50	0.9995
LOWER	2050	1.024	0.77	0.9989
MEDIAN	2100	1.007	-2.02	0.9989
MEDIAN	2050	0.970	-2.22	0.9995
UPPER	2100	1.000	0.50	0.9993
UPPER	2050	0.976	-0.13	0.9986